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Application of the comparative methodology for the definition of individual building elements energy requirements in Italy

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Abstract

Directive 2010/31/EU establishes that Member States must ensure that minimum energy performance requirements for buildings as well as for individual building elements are set with a view to achieve cost-optimal levels. The comparative methodology is here applied to two reference buildings; different energy efficiency measures are considered one at a time in order to find the optimality in terms of costs/benefits; results are then discussed. The definition of the individual building elements refurbishment cost/benefits effectiveness wants to address building administrations to define suitable energy requirements as well as economic incentives, as to promote the energy consumption reduction according to EU requirements.

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Keywords: cost optimal analysis; energy efficiency measures; building elements refurbishment.

1. Introduction

European Directive 2010/31/EU [1] required Member States (MS) to introduce at a national level a comparative methodology framework to define cost-optimal levels of minimum EP requirements for buildings and building elements and compare them with the national requirements set in building codes. According to the Commission Delegated Regulation (EU) No 244/2012 [2] and Guidelines [3] MS performed cost-optimal analysis at national level and results have been published [4]. Recent researches have concerned the definition of national reference buildings [5], the optimization of the comparative methodology [6-8] and the application of the cost-benefit analysis to single case studies and building stock [9]. Starting from the outcomes of previous studies in which energy

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efficiency measures and related costs were identified for several reference buildings, climatic conditions and different economic scenarios [10], the present work focuses on the application of the cost optimality to the single building elements as to define the most suitable refurbishment strategy in terms of energy saving and costs reduction. Two Italian existing reference buildings different in use have been considered; the actual energy consumption and referred costs have been defined and then compared to those coming out from the cost optimality application, both for the building as a whole and for single building elements. The definition of the individual building elements refurbishment cost/benefits effectiveness wants to address central and local governments to define suitable energy requirements as to promote the energy consumption reduction according to EU requirements.

Nomenclature

A	area (m^2)
C	cooling (-)
COP	coefficient of performance (-)
DHW	domestic hot water
EEM	energy efficiency measure
EEO	energy efficiency option
EER	energy efficiency ratio (-)
EP	energy performance (kWh m^{-2})
F	factor (-)
HDD	heating degree days (°C d)
U	thermal transmittance (W $m^{-2}K^{-1}$)
V	volume (m^3)
W	power (W)
η	efficiency (-)
τ	transmission coefficient (-)

Subscripts/Superscripts

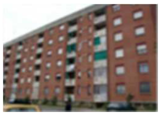
C	control (illuminance)	lgt	lighting
coll	solar collectors	n	net
D	daylight	O	occupancy
env	envelope	p	peak (PV system)
f	floor	PV	photovoltaic (system)
fl,lw	lower floor	rg	control (system)
fl,up	upper floor	ru	heat recovery unit
g	gross	sh	shading
gl	global	W	domestic hot water
gn	generation (system)	w	windows
H	heating	wl	wall (opaque)

2. The comparative methodology framework

2.1. The reference buildings

Two reference buildings among those introduced in previous works [4, 10] have been considered for the Italian climatic zone E (Milano – 2404 HDD) chosen as representative for the geographic extension and the building amount. The first reference building is an apartment-block taken from the Italian “National Building Typology”, as developed in the Intelligent Energy Europe TABULA project [11]; the second reference building is an office building-type as defined by ENEA [12]. Both the buildings were constructed in the period ranging from 1977 to 1990; the main geometric data are reported in Table 1.

Table 1. Reference buildings main geometric data.

Reference building		V_g [m^3]	$A_{f,n}$ [m^2]	A_{env}/V_g [m^{-1}]	A_w/A_{env} [-]	no. of floors	no. of units
Apartment-block		12 685	3 506	0.37	0.08	6	48
Office		7 200	2 007	0.32	0.21	5	70

2.2. The energy assessment and the global cost evaluation

The annual global primary energy needs to fulfil the user's requirements - including heating, cooling, hot water, and ventilation and lighting for offices – is calculated according to CEN standards as implemented by the Italian technical specifications UNI/TS 11300 [13]. EP_{gl} is thus defined as the non-renewable primary energy necessary to satisfy the building energy needs for the end uses considered; the conversion factor in primary energy for natural gas is 1.0 and for electricity is 2.174 [14]. The exported energy is not taken into account. The investigations is based on equivalent thermal and visual comfort conditions. The cost-optimal methodology framework is based on the net present value (global cost) calculation, according to Standard EN 15459 [15], considering an estimated economic lifetime of 30 years for the residential buildings and 20 years for the offices, a discount rate of 4%, and applying a financial calculation level. The initial investment, the sum of annual costs for every year (energy, maintenance, operational and added), the extraordinary substitution (components and systems) and the final value as well as disposal costs if appropriate have been defined. The energy cost optimization tool based on a sequential search-optimization technique already developed in previous works [9] is used in order to perform the cost-benefit analysis finalized to the definition of the reference buildings optimal level.

2.3. The energy efficiency measures

The set of energy efficiency measures (EEMs) already defined by the Italian Ministry of Economic Development [4] and by Corrado et al. [10] were applied to each reference building. An appropriate parameter is associated to each measure (e.g. the U-value for the thermal insulation of the building envelope) and up to five energy efficiency options or levels (EEOs) are defined for each measure. The first EEO level usually represents an inefficient solution used as a test value; the second level corresponds to the requirement fixed by current legislation [16]; the levels from the third to the fifth (if applicable) are more efficient solutions. The lists of the EEOs for each EEM are reported in Table 2 for the building elements and systems; in the table the reference buildings EEO optimal levels are shown too.

An initial investment cost value is associated to each EEO; this value includes design, purchase of building elements, connection to suppliers, installation and commissioning processes. The EEOs costs as well as the energy costs were got both by extensive market surveys and by analysing official databases [4,10].

3. Results and discussion

For each reference building both the global energy performance index EP_{gl} and the global cost have been calculated for the state-of-the-art (Base case) and the results have been compared to those obtained from the cost-optimal methodology application to a building major refurbishment (Optimal case). Thus, the single retrofit measures EEMs and referred performance levels (from EEO 1 to EEO 5 if relevant) have been considered. The results are shown in Fig. 1 for the residential building and in Fig. 3 for the office, split by energy use. It is possible to distinguish the energy added value given by single EEM versus the major refurbishment considered in the Optimal case. As well, Figs 2 and 4 compare the global costs for the Base and the Optimal case with those obtained by single energy retrofits.

Table 2. Energy efficiency measures levels and reference buildings state-of-the-art and optimal values.

EEM		EEO					Optimal EEO [10]	
		1	2	3	4	5	Residential	Office
1.Exterior wall thermal insulation (exterior)	U_{wl} [W m^{-2} K^{-1}]	0.45	0.34	0.29	0.25	0.20	0.34	-
2.Exterior wall thermal insulation (on cavity)								
- Residential	U_{wl} [W m^{-2} K^{-1}]	0.49	0.32				-	-
- Office		0.34	0.22				-	0.22
3.Roof thermal insulation	$U_{fl,up}$ [W m^{-2} K^{-1}]	0.40	0.30	0.27	0.23	0.20	0.30	0.27
4.Floor thermal insulation (for Residential only)	$U_{fl,lw}$ [W m^{-2} K^{-1}]	0.45	0.33	0.29	0.24	0.20	0.45	-
5.Window thermal insulation	U_w [W m^{-2} K^{-1}]	5.00	2.20	1.90	1.60	1.30	1.60	1.60
6.Solar shading devices	τ_{sh} [-]	0.4	0.4				0.4	0.4
Movable (M) or Fixed (F)	M *or* F	M	F				F	F
7. + 8. + 9. (for Residential only)	$\eta_{H,gn}$ *or* COP [-]	0.88	0.98	1	3.69	4.13	-	-
Heat generator for space heating + Heat generator for domestic hot water + Chiller	$\eta_{W,gn}$ [-]	0.88	0.98	1			-	-
	EER [-]	3.20	3.86	4.20			-	-
or 10. + 9. Combined heat generator for space heating and domestic hot water + Chiller (for Residential only)	$\eta_{H,W,gn}$ [-]	0.88	0.98	1.00			-	-
	EER [-]	3.20	3.86	4.20			-	-
or 10. + 9. Combined heat generator for space heating and domestic hot water + Chiller (for Office only)	$\eta_{H,W,gn}$ [-]	0.88	0.94	1.03			-	0.94
	EER [-]	3.50	4.00	5.00			-	4.00
or 11.Combined generator for heating, cooling and domestic hot water	COP [-]	2.50	2.90	3.30			3.30	-
	EER [-]	2.40	2.80	3.20			3.20	-
12.Thermal solar system (for Residential only)	A_{coll} [m^2]	58	96	134			58	-
12.Thermal solar system (for Office only)		10	-	-			-	10
13.Photovoltaic system (for Residential only)	W_{PV} [kW$_p$]	4	9	13	17		4	-
13.Photovoltaic system (for Office only)		6	12	18	20		-	20
14.Heat recovery ventilation system (for Office only)	η_{ru} [-]	0.6	0.7	0.9			-	0.6
15.Efficiency of the heat control system	η_{rg} [-]	0.94	0.97	0.995			0.995	0.97
16.Lighting (for Office only)								
16.Lighting power density	W_{lgt} [W m^{-2}]	15.0	13.0	4.70	4.60		-	4.60
16.Lighting control system parameters	F_O [-]	1.0	0.9	1.0	0.8		-	0.8
	F_C (F_D) [-]	1.0	0.9	1.0	0.9		-	0.9

While for the optimality evaluation a whole building renovation has been considered, in case of single energy retrofit only non-invasive measures have been applied; thus, when a centralized heating system and a single DHW system for each floor/unit were installed in the Base case, the only EEMs considered were those maintaining heating and DHW separated. Furthermore, the floor thermal insulation were not be considered for the office because of technical impediments as the first floor is directly on the ground. The results show an EP_{gl} substantial reduction when the major renovation is considered (Optimal case) both for the residential building (62%) and for the office (71%), while the referred global costs are 351 € m^{-2} and 517 € m^{-2}, 45% and 24% higher than the Base case for the residential building and for the office respectively. When a single retrofit measure is applied to a building component, the most consistent energy consumption reduction for heating is of 13%, corresponding to an high insulation level for the vertical opaque component (EEM 1.5) or for the windows (EEM 5.5). But if the costs are also considered, while the high insulation of the vertical opaque component does not show robust differences with respect to the Base case, the windows replacement with high performant ones is not economically sustainable, especially for the office with an increasing global cost of 30%.

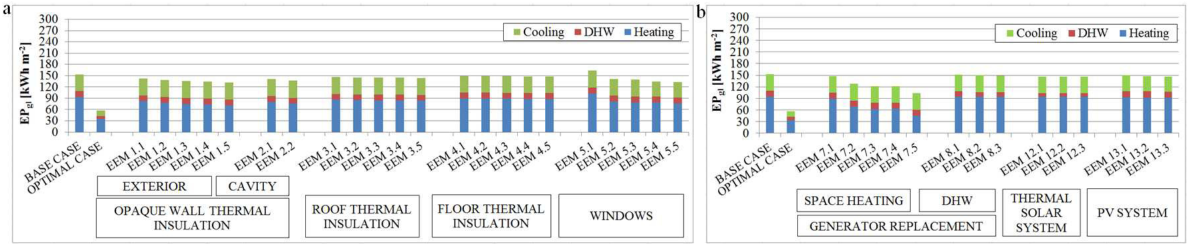


Fig. 1. Global primary energy performance index for the residential building: envelope components (a) and technical systems (b) retrofit.

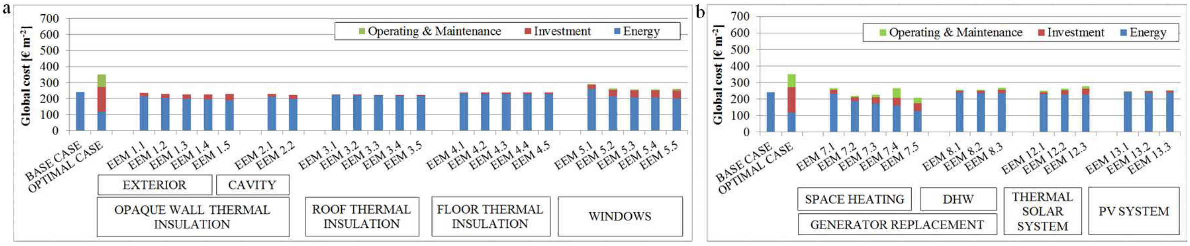


Fig. 2. Global cost for the residential building: envelope components (a) and technical systems (b) retrofit.

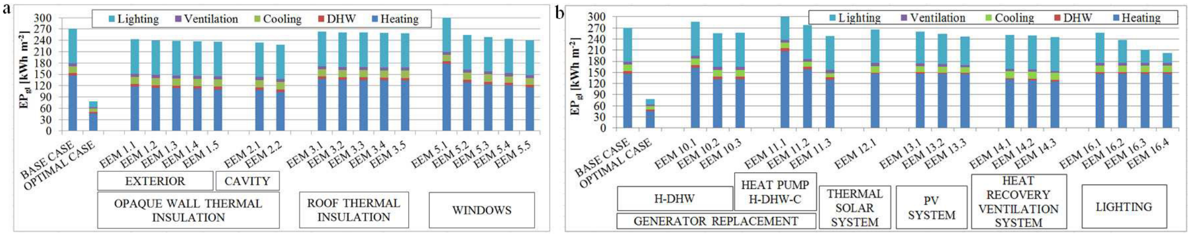


Fig. 3. Global primary energy performance index for the office building: envelope components (a) and technical systems (b) retrofit.

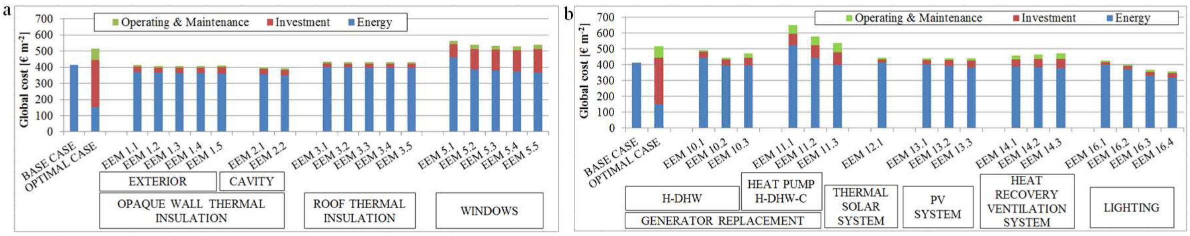


Fig. 4. Global cost for the office building: envelope components (a) and technical systems (b) retrofit.

By considering single retrofit measures on the building technical systems, it is noticed that for the residential building the space heating generator replacement with an high heat pump (EEM 7.5) leads to a 32% EP_{gl} and a 14% Global cost reduction, while the use of renewable sources does not affect substantially the energy consumption because the solar collectors are only used for DHW and the electricity consumption for the residential technical systems is not significant. Concerning the office, the use of a centralized heat pump (EEM 11.3) reduces as well the

EP_{gl} of about 9% but with a Global cost similar to that of the Optimal case because of the high electricity consumption in absence of PV panels; the use of the heat recovery ventilation system as well as the PV panels obtain similar results in terms of both EP_{gl} and Global cost. Finally, the replacement of the old lighting system with a high efficient one obtains the 24% saving energy and a 13% reduction of the global cost with respect to the Base case.

4. Conclusions

In the present work two Italian existing reference buildings placed in Milano and different in use (residential and office) have been considered; the actual energy consumption and referred costs have been defined and then compared to those obtained from the cost optimality application, both for the building as a whole and for single building elements. Against an higher global cost of about 150 € m^{-2} with respect to the base case, the major renovation shows a reduction of the primary energy consumption of more than 60% for both the residential building and the office. That results point out the need of synergy among different retrofitting energy efficiency measures in order to optimize energy performance and costs reduction. The results show the EEMs up to the actual energy requirements are generally sustainable both in terms of energy consumption and global cost; only the windows replacement shows too high investment costs with respect to the resulting energy saving. An useful economic incentive could be the finalized to the combined use of high efficient heat pumps and PV panels.

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